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Psychological Monographs: General and Applied

Effects of Ionized Air and Electroconvulsive Shock on Learning and Innate Behavior in Rats[1]

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I. The Problem

A. *Introduction*

The studies herein reported involve tests of whether negatively and positively ionized air produce differential effects on the maze-learning and nest-building behavior of male albino rats. Involved, also, are tests of the possible effectiveness of ionized air in counteracting or ameliorating the deleterious effects which electroconvulsive shock (ECS) has on maze behavior and nest-building activity. By studying the effects of ionized air and of shock on the mechanisms for both learned and innate behavior in animals, perhaps a contribution toward a better understanding of the use of ECS and of ionized air as clinical tools may be made.

Near the turn of the present century speculation began as to what effects, if any, variations in ionization of atmospheric particles might have on human well-being. There were minor studies in the next two decades, but it was not until the thirties that reports of extensive research by German, Russian, and American scientists appeared. The publications on this topic have been reviewed by Bauer (1).

In recent years the study of artificial ionization of air has received renewed emphasis through a comprehensive research program sponsored by the Wesix Electric Heater Company of San Francisco. This has led to research on engineering problems related to artificial ionization and to biological, physiological, and psychological studies of possible effects of ionized air on living organisms. The present study by the author is part of the psychological phase of that research program.

Though some of the early studies on ionization dealt with ionized air in which the positive and negative charges were not separated, the general trend in research on this problem has been to test for possible differential effects produced by positive and negative ions. Following the precedent of Dessauer (11) and Chizhevskii (5, 6, 7, 8, 9), generally it has been postulated that positive ions will produce undesirable physiological and biological effects and unpleasant subjective symptoms. Also, quite generally it has been postulated that negative ions produce desirable physiological and biological effects as well as feelings of exhilaration and well-being in human subjects.

The hypotheses above have been supported most definitely by the research of Dessauer, Chizhevskii, and their associates, but there have been serious challenges of the reliability of that research. Generally in those studies there is little or no evidence that adequate controls were maintained, and the reporting of data usually was not complete enough to permit an evaluation of the statistical significance of the results. Many of the basic premises were not tested and many of the claims were generalizations not sup-

[1] This paper is an abridgement of a dissertation submitted in 1953 to the Department of Psychology, Stanford University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The author is indebted to Dr. Calvin P. Stone under whose guidance the experiments were conducted. He also acknowledges indebtedness to Dr. Clifford T. Morgan and Dr. Douglas H. Lawrence for advice during the course of the study. This study was supported by grants from the Wesix Electric Heater Company of San Francisco and from the Scottish Rite Fund for research on the effects of electroconvulsive shock on the behavior of animals.

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ported by sufficient published data. Therefore, the claims based on those studies cannot be accepted unless supported by properly controlled and more fully reported research.

In carefully controlled and well-reported studies, Herrington and his associates (15, 16) and Yaglou and his associates (30, 31, 32) repeated some of the specific techniques of Dessauer and Chizhevskii but failed to find conclusive evidence of effects that could be ascribed to artificial ionization of the atmosphere. However, a need for further investigation was indicated. Some of the later growth studies (4, 10, 18) have suggested the possibility of ionization effects, but none has been conclusive. Other recent biological and physiological studies (19, 26) have presented data allegedly indicating effects produced by differential ionization of the air, but they are not likely to be accepted widely as confirmatory of the claims for the effects of ionized air until they have been successfully repeated.

Since the question of possible effects of ionized air is one of some concern to air-conditioning engineers and to hygienists and therapists, there is need for a concerted attack on the problem. Such an attack involves not only repetition of older methods which appeared promising, but attacks on new fronts as well. The proposed psychological tests, then, may be considered a new approach to an old problem, and a contribution to a broader program under which biological and physiological aspects of the problem are also being currently investigated. If the proposed tests should measure differences in behavior under differential conditions of ionization, this would suggest that there are ion-induced changes, as yet unmeasured, in underlying physiological and biological processes.

B. *Design of the Maze-Learning Experiment*

To test the hypothesis that differential effects on living organisms can be produced by positively and negatively ionized air compared *inter se* and with normal room air, a maze-learning experiment was designed. In addition to the differential ionization variable, a second variable, electroconvulsive shock (ECS) versus pseudoshock, was included in the experiment. A factorial design permitted a simultaneous study of the effects of ECS and of the effects of atmospheric ionization. It also provided a test of whether the deleterious effects produced by ECS and the rate of recovery from such effects could be modified in any way by having *Ss* live in unipolarly charged air. The following six groups met the demands of the experimental design:

Group I: White rats living in positively ionized air and subjected only to pseudoshock.

Group II: White rats living in positively ionized air and subjected to ECS.

Group III: White rats living in negatively ionized air and subjected only to pseudoshock.

Group IV: White rats living in negatively ionized air and subjected to ECS.

Group V: White rats subjected only to pseudoshock and living in normal air which usually contains only a small and approximately equal number of ions of both kinds.

Group VI: White rats subjected to ECS and living in normal air.

That maze learning is both feasible and useful as an indicator of changes in biological and physiological processes is indicated by its extensive use in testing beneficial or harmful effects of foods, drugs, endocrine conditions, etc. in rats (22, pp. 341-348). Also, the fact that a behavioral deficit can be experimentally established in rats by the use of ECS has been clearly proven by the experiments reviewed by Munn (22) and by Morgan and Stellar (21). These show that white rats which were subjected to a course of ECS during the learning period had a significantly slower rate of maze learning than normal rats. When the course

of ECS was discontinued, they gradually recovered from its effects and, if training was continued, eventually reached the criterion of learning that was earlier attained by the nonshocked controls.

If rate of maze learning can serve as an index of physiological changes which allegedly are produced by ionized air and/or by ECS, the following predictions should be borne out by the results of this experiment:

1. Considering the over-all results, negatively ionized air should have a beneficial or facilitative effect, and positively ionized air, a detrimental or retarding effect on learning.
2. In terms of over-all results, the rats subjected to a course of ECS should be significantly slower in learning than the normal rats.
3. Comparing Groups I, III, and V, one should find that learning by Group III (exposed to negative ions) will be most rapid and that for Group I (exposed to positive ions) will be least rapid.
4. Comparing Groups II, IV, and VI, the rate of learning and/or the rate of recovery from the ECS should be most rapid for Group IV (exposed to negative ions) and least rapid for Group II (exposed to positive ions).

C. *Design of the Nest-Building Experiment*

To provide more inclusive tests than maze learning alone would give, a study of nonlearned behavior was designed. Stone and Walker (27, 28) have shown that nest building, a form of innate behavior in rats, is disrupted by a course of ECS. Furthermore, as in learning experiments, while the rats gradually recover from the effects of ECS, nest building gradually returns to normal. By periodic ratings of the nests, the initial deficit and rate of recovery of the animals from the effects of the ECS can be measured. Thus, in the present investigation the method of Stone and Walker offers another means of testing whether negatively ionized air facilitates the rats' recovery from the effects of ECS, thereby supporting claims of beneficial therapeutic effects cited in the literature. Also, it may be a means of finding out whether positively ionized air retards recovery from cerebral damage.

To make these tests, the following experimental design, involving five groups of male rats, was used:

Electroconvulsive Shock Groups: (Tested while living in small enclosed chambers or boxes in which atmospheric ionization was controlled.)

Group A: An experimental group in positively ionized air in an enclosed chamber.

Group B: An experimental group in negatively ionized air in an enclosed chamber.

Group C: An ECS control group in normal air in an enclosed chamber.

Nonshock Groups:[2]

Group D: A nonshock control group in normal air in an open room.

Group E: A nonshock control group living in normal air in the enclosed chambers which previously had housed Groups A, B, and C.

If ionized air can either facilitate or hinder recovery from the deleterious effects of ECS, then, provided that the nest-building test is a suitable measure of the changes effected in the rat by ionized air and/or by ECS, the following predictions should be supported by the results of the tests:

1. The average ratings of nests built by male rats in this experiment should be significantly lower for the ECS groups than for nonshock groups during and immediately after the shock period.
2. As recovery from shock occurs, the ratings of nests for *Ss* in the ECS groups should approach the ratings for the nonshock groups.

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[2] The *Ss* in the first nonshock control group, Group D, lived in individual cages in an open room, whereas *Ss* in the three simultaneously tested ECS groups lived in cages within small enclosed chambers placed in the same room. To determine whether the enclosed chambers, per se, produced any effects on nest building behavior, the second nonshock control group, Group E, was used.

3. In comparing Groups A, B, and C, Group B (negative ionization) should show evidence of protection from the deleterious effects of ECS or should recover more rapidly from those effects than Group A or Group C. Group A (positive ionization) should show most evidence of a behavior deficit and/or should be slowest to recover from the effects of the ECS.

II. Subjects, Apparatus, and Experimental Setting

A. *Subjects*

The *Ss* in Groups I-VI of the maze-learning experiment comprised 138 experimentally naive male albino rats, descendants of a local strain derived from Wistar stock. Their ages ranged from 60 to 170 days at the beginning of preliminary training. They had been tamed by being handled each day for 10 days before the experiment started.

For the convenience of the experimenter, the maze-learning experiment was conducted in four phases. In the first phase there were 5 *Ss* in each of the subgroups ($N = 30$); in each of the three other phases or replications, there were 6 *Ss* in each of the 6 subgroups ($N = 108$). To replace losses[4] that occurred, additional animals were added as needed in each replication. A total of 23 *Ss* had been included in each group by the end of the maze experiment.

In assigning *Ss* to experimental and control groups in the maze experiment, a split age group technique was used. Thus, the groups were approximately equated for age and for weight at the beginning of the project and the litters were well distributed among the groups.

[4] During the course of the experiment 15 rats died. Ten of these deaths were due directly to the electroconvulsive shock or to paralysis following the convulsion. There was no indication that any of the deaths were in any way related to possible effects of ionized air. Also, in experimental results there was no evidence of any bias caused by the deaths.

The *Ss* in the nest-building experiment were 48 of the males which previously had been used in the maze-learning experiment, divided equally among Groups A, B, C, and D. At the beginning of the nest-building experiment they ranged in age from 110 to 220 days. Animals which had been shocked in the maze experiment had 30 days or more to recover from the first ECS series before beginning the series of ECS for the nest-building experiment. This is more than sufficient time for full recovery. Animals of Group D, a nonshock group in this experiment, were selected from the *Ss* which had not been shocked during the learning experiment. Group E consisted of 12 white males which had been tamed by handling but previously had not been used in any other experiment; they ranged in age from 105 to 115 days.

During maze and nesting experiments all animals had continual access to food (Purina Dog Checkers) and water. This diet was supplemented occasionally by lettuce and carrots. Also in each cage was fastened a small block of "Leslie Salt Petlick." The objective was to produce optimal conditions for growth and health for all animals throughout the study.

B. *Apparatus and Experimental Setting*

Living cages and atmosphere-control chambers. Ionization of the air surrounding the *Ss* is an important variable in this experiment. Therefore, three plywood boxes (54″ × 30″ × 30″) were built to provide the rats with living space in which ionization could be controlled. Each of these atmosphere-control chambers (see Fig. 1) was large enough to hold four cages (24″ × 18″ × 12″) constructed of ½-in. mesh galvanized wire and with floors of galvanized sheet iron. The chambers had framed glass doors which opened outward. Each chamber was ventilated by a small blower so mounted on the top of the box that air was discharged down into the chamber in front of the cages at the rate of three to four cubic feet per minute. After circulating in the chamber the air escaped through ½-in. holes in the rear wall.

During the maze-learning experiment all *Ss* were housed in the atmosphere-control cham-

bers but during the nest-building experiment only Groups A, B, C, and E lived inside the chambers. Group D did not live in an atmosphere-control chamber owing to a shortage of this type of enclosure. For that group, four cages (24″ × 18″ × 12″) were assembled in the laboratory room in two tiers, similar to the arrangement in the chambers. A partial enclosure similar in proportions to the walls of the chambers was set up around the four cages to shut out an equivalent amount of light, but there were no doors on the front of the enclosure. Therefore, the living space of Group D was open to free circulation of air from the laboratory; but in terms of air ionization, conditions for Group D were essentially like those maintained within the chambers while Group E was being tested.

Occupancy of each of the three chambers was rotated among the ECS groups (A, B, and C) during the three replications of the experiment which concerned them. Thus, variables such as small differences in amount of light which entered the chambers were controlled.

During the maze-learning experiments the temperature of the laboratory was controlled so that the rats were not exposed to extreme maximum or minimum temperatures. Also, in the nest-building experiment during the preliminary ECS intervals, temperatures were maintained at levels that were not conducive to nest building and no nesting material was supplied. But during each nest-building period the principal room heater was turned off so that the room would become cold enough to motivate nest building maximally. Only a thermostatically-controlled electric heater was used to prevent extreme temperature decreases at night so that shocked animals which did not build nests would not die of exposure. During the nest-building periods daily minimum temperatures ranged from 45.5° to 61° F with a mean of 52.2° F and daily maximum

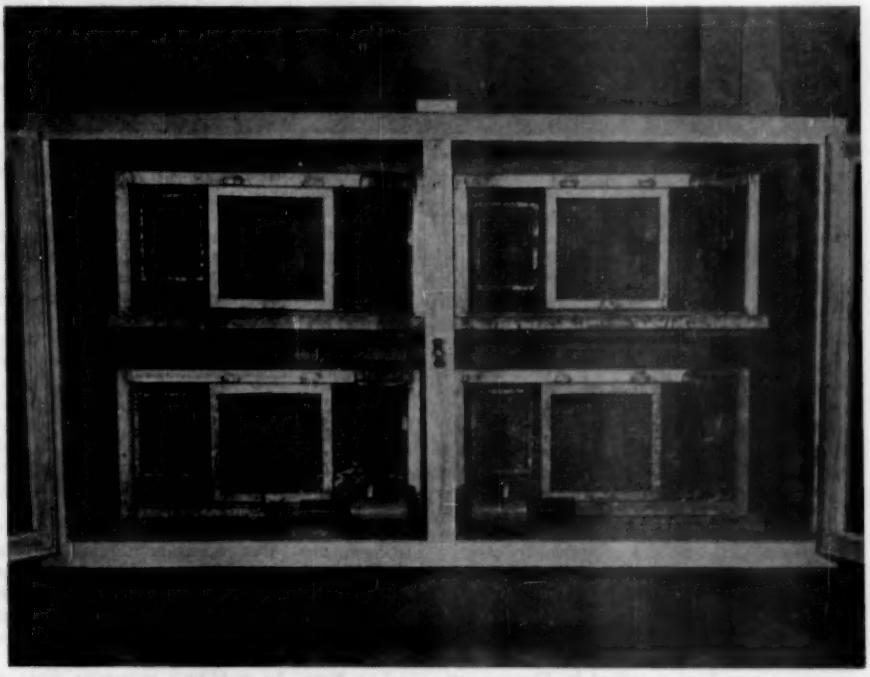

FIG. 1. An atmosphere-control chamber. The position of the ion generators can be seen in the foreground. On the top of the chamber is the blower which provided ventilation when the doors were closed. Nesting material in the cages is visible. When rats lived in these cages during the maze-learning experiment, no nesting material was provided, but the floors were covered with approximately ½ in. of sawdust.

temperatures ranged from 61° to 89° F with a mean of 73.6° F.

The ion generator. To provide unipolarly ionized air for the experimental groups, polonium-source ion generators were used.[5] Two positive ion generators were placed in the chamber in which Groups I and II lived and two negative ion generators in the chamber of Groups III and IV. Each generator consists basically of a small piece of commercially prepared polonium foil, a sleeve electrode which can be either negatively or positively charged, a small selenium rectifier, and a small fan which moves about one-half cubic foot of air per minute through the sleeve electrode.

The sleeve electrode is a stainless steel tube 1¾ in. long. It is connected to a terminal of a tiny selenium rectifier which in turn is connected to a standard 120-v. alternating current. The sleeve electrode becomes charged either positively or negatively with about 100 v. rectified current, depending on whether it is connected to the positive or the negative pole of the rectifier.

The piece of radioactive polonium foil is about 1 in. square and initially comprises 1½ MC. It is located ⅞ in. from the outlet end of the sleeve electrode which extends above the base of the unit. The polonium 210 radiates numerous alpha particles which create both positive and negative small ions by collision with air molecules.

The separation of ions and the elimination of those unwanted is done by the charged sleeve electrodes. In a negative ion generator the sleeve is negatively charged so that it will attract the unwanted positive ions and will collect or neutralize them. At the same time, negative ions are repelled by that negatively charged sleeve and driven toward the open end of the sleeve where they escape into the chamber in which negatively ionized air is desired.

In a positive ion generator, the sleeve electrode is positively charged so that it will collect the unwanted negative ions and repel the positive ions. The positive ions escape into the chamber in which positively ionized air is desired. Ozone, nitrous oxides, or other undesirable substances are not produced by these ion generators.

The ion collector. The ion collector, used to measure the concentration of ions in the atmosphere, was designed and built for the Wesix Electric Heater Company of San Francisco. The principles for the construction and use of the apparatus have been described by Fleming (13). Basic to such equipment is a duct or tube through which air is drawn across a series of carefully insulated, charged plates. By controlling the charge on the plates, the machine can be set to collect either negative or positive ions. The collection of ions on the plates results in a flow of current that is measured by a sensitive ammeter. By use of specially prepared tables, readings on the ammeter are converted to measures of the number of ions per cubic centimeter of air.

At spaced times, during the course of the maze-learning experiment, 13 measurements of the ion content in each of the three chambers were made. The medians of those measurements may be considered representative of ion densities prevailing during the course of the experiment. Median values of 6000 positive ions and 250 negative ions in the positive chamber indicated that the required marked predominance of positive ions was maintained there. Medians of 3500 negative and 250 positive ions in the chamber to be negatively ionized gave assurance that the required predominance of negative ions was maintained in that chamber. In the normal air in the control chamber the medians of the measurements indicated 300 positive and 350 negative ions. Since the difference was within the range of machine and observer errors, we may assume that a small and approximately equal number of ions of both kinds was present as expected in the normal room air in the control chamber.

During the nest-building experiment, eight measurements were made of the ion content in each of the three chambers and in the open room in which Group E lived. The median measurements were considered representative of ion densities prevailing during the course of that experiment. The medians for the positively ionized chamber were 6500 positive ions and 150 negative ions. The medians for the negatively ionized chamber were 3000 negative and 150 positive ions. The medians for the normal air in the control chamber were 150 positive and 150 negative ions. The medians for the normal air in the open room were 350 positive and 350 negative ions.

Apparatus for administration of ECS. Electroconvulsive shock was administered with a Pittsburgh Electroshock Unit. This equipment provides a control of the current which is applied to induce a convulsion. The apparatus has been described in detail by Russell, Pierce, Rohrer, and Townsend (23).

The Maze. An eight-unit swimming maze, a modified version of Warden's multiple-U design, (29, p. 239), was used in the learning study. A water maze was chosen to provide motivation for learning without introducing physiological varia-

[5] The ion generators were provided by the Wesix Electric Heater Company, 390 First Street, San Francisco, California.

bles such as pain, strong hunger, or thirst—external incentives frequently used to motivate the learning of floor mazes. Since the problem is concerned with whether ionized air produces biological and physiological effects which could affect learning, it was preferable not to complicate it by inducing pain, intense hunger, or thirst.

Details of the design and dimensions of the maze are presented in Fig. 2. In addition to the multiple-U maze, there was a long, straight alley which was used for preliminary training. That alley was 10 ft. long, 5 in. wide, and 14 in. high. It had no connection with the U maze. All units were made of galvanized steel and stood in 7 in. of water in a copper tank.

The mean temperature of the water in the maze during the first two phases of the experiment (January 10 to February 26, 1952) was 59°F, with a range from 56° to 62°F; the range of the air temperature of the maze room was 67° to 74°F, with a mean of 69°F. During the last two replications of the experiment (April 19 to May 31, 1952) that of the water was 63°F, with a range from 59° to 66°F, and that of the maze room was 68° to 83°F, with a mean of 75°F.

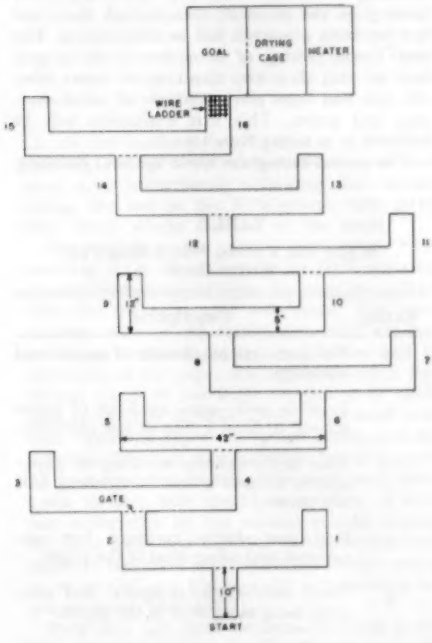

FIG. 2. Floor plan of the maze. The internal measurements of the units are indicated on the diagram. The maze walls were 14 in. high. There were guillotine-type doors at each choice point.

Some illumination in the maze room was provided by two small opaque windows on one side of the room, but the principal source of light was a 120-w. fluorescent unit located directly over the maze, about six ft. above the water.

III. Experimental Procedure

A. *The Maze-Learning Experiment*

Preliminary training. On the day the *S*s were placed in the atmosphere-control chambers, the preliminary training also was started. For five successive days each *S* was given two trials per day swimming through the straight, 10-ft. alley. The purpose of the preliminary training was to familiarize the rats with water and the learning situation without giving specific knowledge of the turns in the maze.

Training on the maze. Following five days of preliminary training, each rat was given one trial daily for 31 consecutive days on the Warden U water maze (Fig. 2). The rat was put into the water in the starting alley where it started swimming in search of the point of escape. As soon as a choice point was passed, the gate was lowered. Though retracing could take place within a unit, the gates prevented re-entry of units already traversed. When the rat reached the end of the last unit, it climbed up the wire ladder to the goal box leading to the warm drying cage.

Time, forward-going errors, and retracings were recorded. Time was measured from the moment the animal was put into the water until it reached the escape ladder leading to the goal box. A forward-going error was tallied if an animal advanced into a blind alley by as much as the length of its body (not including the tail). If the animal first entered the correct alley, but then retraced as far as the closed gate or to the end of the blind alley, a retracing error was recorded. When a unit was retraced repeatedly, as sometimes occurred with shocked animals, an error was recorded for each retracing.

After all animals of a subgroup had completed their trials, they were returned to the home room. There they were dried near a heater before being replaced in their home cages in the ionization and control chambers. During the hour which the maze trials and drying consumed, the *S*s of Groups I, II, III, and IV were not in unipolarly ionized air; but they were subjected to appropriately ionized air for the remaining 23 hours before the next day's trials started.

The electroconvulsive shock period. Following

each of the first 10 trials on the maze, the rats in Groups II, IV, and VI received an electroconvulsive shock just before being replaced in their home cages. The schedules were so arranged during that period that each shock was given approximately 30 min. after the maze trial for that day was completed. One rat at a time was lifted out of the drying cage in the experimenter's left hand. A loose white cotton glove was worn for this handling so that any fear associated with the shock experience would tend to generalize less to other handling which was done with bare hands. While the rat was held on the table, small spring clips with padded jaws were fastened to its ears. The padded clips had been moistened in a saturated solution of bicarbonate of soda to lower skin resistance. The rat was released from the left hand just a moment before throwing the switch to release the current of the Pittsburgh Electroshock Unit (23), which had been set to allow a current of 50 Ma. to flow for 0.2 sec.

Typical tonic-clonic convulsions were produced (14). As soon as the convulsion started, the ear clips were removed and the animal, while still convulsing, was quickly placed in its home cage. Thus, convulsed animals of the ionization groups were in appropriately ionized air as soon as they resumed breathing in the postconvulsion period, and there they remained for about 23 hr. without further disturbance.

Following trials 1 to 10 the nonshock groups received equivalent handling but only "pseudoshock," a term that seems appropriate because they were placed on the shock table and clips were fastened to their ears, but the electric current was not turned on; hence, no convulsions occurred.

B. *The Nest-Building Experiment*

Subjects in Groups A and B, living in appropriately ionized air, and Group C, living in the normal air chamber, were given a series of electroconvulsive shocks—one each day for 10 days. During the first eight days of the shock period, room temperatures were high enough so that the male rats of all groups would have had little or no need for nesting to conserve heat. None had had any previous experience in nest building since no nesting material had been provided up to that time.

After the ninth shock for rats in Groups A, B, and C, each of those animals and the ones in Group D (not shocked) were given a supply of material for nest building. First, approximately 350 gm. of dry wood shavings were spread evenly on the floor of the cage, making a layer about ½-in. deep. Then 60 gm. of shredded paper (strips of newsprint ⅛ to ¼ in. wide) were scattered loosely and evenly over the shavings. Nesting material was placed in the cages at about 2:00 P.M. on the ninth day of the course of shocks. Room heaters then were turned off and windows opened during the daytime and some of the warmer nights. Under these conditions daily minimum room temperatures ranged between 45.5° and 61°F. The normal daily temperature fluctuations provided the isolated rats with an adequate incentive for nest building.

In order to make a statistical comparison of the differences in nest building by the various groups of rats, a rating scale was needed. The scale which had been used successfully by Walker (28, p. 17) was modified slightly for this study. It is presented in Table 1 and illustrated in Fig. 3 and 4. Bauer (1, pp. 66, 68, and 70) presents additional photographs illustrating use of the scale. When the scale was used, the symbols, plus (+) and minus (−), were used with the numbers to indicate finer gradations in the ratings.

Informal observations showed that some normal, nonshocked rats were moving paper and building nests less than two hours after they were given the material—even though there had not yet been a marked fall in temperature. The first formal rating of nests was made at 9:00 P.M. of that day, i.e., about seven hours after the rats had been given a supply of wood shavings and paper. This first evaluation will be referred to as rating Number 1.

The second rating was made the next morning,

TABLE 1

SCALE FOR RATING NESTS BUILT BY WHITE RATS

Rating	Description
0	No nest—no movement of paper and shavings
1	Possible nest—some evidence of paper moved to form a ring or low platform.
2	Poor nest—definite evidence of paper moved to form a nest using about half the paper.
3	Fair nest—fairly compact but uncovered nest using most of the paper.
4	Good nest—high, compact, and covered, using most or all of the paper.
5	Excellent nest—a very high, compact, well-covered nest using all of the paper, and in addition having a large proportion of the shavings swept up around the base.

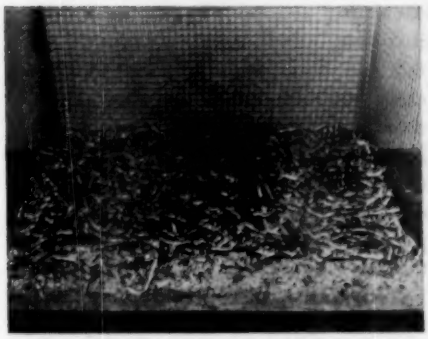

FIG. 3. An illustration of the rating of "0" (zero) on the nest-rating scale (Table 1). This photograph was made on the third morning of the nesting period. A rat which had received 10 electroconvulsive shocks had lived in that space for about 80 hr. However, it had made no attempt to build a nest even though the temperature in that period had fallen to a minimum of 53.5°F. The paper had become somewhat flattened and packed down by the activity of the rat, but there had been no movement of paper and shavings to a nesting site. There were only slight depressions in the corners where the rat had been sitting.

FIG. 4. Illustrating ratings of 4 and 5 on the nest-rating scale (Table 1). The nest in this photograph was in a transition stage between a 4 and a 5. It was rated 4+ when photographed. If a larger proportion of the wood shavings had been utilized, it would have been rated 5— or 5.

i.e., on the tenth day of the course of ECS. All morning ratings were made between 9:00 and 10:15 A.M. Immediately following that second rating, the rats in the ECS groups were given their tenth shock, the last of the series.

For six days the nests were rated each morning. After the rating on the sixth morning the rats were removed from the cages for a short time and the nests were torn apart. The wood shavings were spread evenly again and wet material was replaced. Approximately one-half to two-thirds of the paper was replaced since it had become damp or too finely shreded to be easily used by the rats to make a fluffy, well-structured nest. Again the paper was spread evenly over the shavings. The rats were replaced in their cages. At 9:00 P.M. that evening the nests were rated again to note how quickly rebuilding of nests was undertaken by the various groups. During the next four days morning ratings were made again at the usual time. With the twelfth rating at 10:00 A.M., one phase of the nest-building experiment was concluded.

Only four rats could be accommodated at one time in each of the ionization chambers during this nesting experiment since only one *S* lived in each cage during the nest-building period; therefore, the above procedure was repeated three times in order to secure data on 12 *S*s for each of the groups: A, B, C, and D. After the tests with those groups were finished, 12 non-shocked male albino rats (Group E) were placed in the 12 cages in the three enclosed chambers with a fresh supply of the usual nesting materials. All were in normal air.

For ratings designated above as Numbers 1 through 4, the procedure for Group E was the same as it had been for Groups A, B, C, and D; i.e., the first evening rating and the first three morning ratings were made as usual. However, ratings Numbers 5, 6, and 7 were omitted. Instead, after the nests were rated on the third morning (rating Number 4) the nests were torn apart and part of the material was replaced as had been done following rating Number 7 with the other groups. This variation from the previous schedule was justified on the ground that these *S*s already had revealed the essential similarity between normal animals inside the chambers and in the outer room. It was now necessary only to compare them on nest reconstruction.

That evening the reconstructed nests of *S*s in Group E were rated again at 9:00 P.M. as had been done for rating Number 8 with Groups A, B, C, and D. For comparative purposes, therefore, that fifth rating for Group E most nearly corresponded to rating Number 8 of the other four groups and was graphed accordingly when the data were analyzed (Fig. 7). On the next three mornings, ratings were made for Group E that most nearly correspond to ratings Number 9, 10, and 11 made for other groups; they are graphed accordingly in the statement of results which follows. This terminated the last phase of the nest-building experiment.

Subjects in all groups varied widely in *how* they used their supply of paper in building a nest. Some used most of the paper to build a firm base or platform leaving little for the sides or to provide a covering for the nest. Others, such as the one whose nest is shown in Fig. 4, used little or no paper for the floor of the nest, but instead had shavings for a base and used the paper to provide a very satisfactory covering for the nest. Some rats which had used all of their paper appeared to have quite incomplete nests simple because too much of the paper had been used to form the base; in such cases, they were then given 10 to 20 gm. of additional paper. Some rats thereupon simply added the new paper to the old base to build a still higher "platform-type" nest. This was still given a rating of 3 because it did not provide cover for the rat. Some of these "platform-type" nests were restructured later in ways that provided better cover for the rat and then a higher rating was given to them.

Besides the ratings made by the experimenter at the intervals described above, independent ratings of the nests were made by Professor Calvin P. Stone. He made 29 morning ratings on 16 nests during the first three phases of the experiment and 3 morning ratings on 12 nests during the fourth phase of the experiment which involved Group E. The purpose of these 500 ratings was to provide data for a test of the reliability of the rating scale.

IV. Results

A. *The Maze-Learning Experiment*

Means of the maze errors and of the time scores for each group of *Ss* and other results of statistical analyses are presented in the tables that follow. After Bartlett's test (24) for homogeneity of variance had been applied, an analysis of variance was made for each set of data by using the method suggested by McNemar (20, pp. 283-289) for a design involving double classification with more than one score per cell. Since all error and time scores made on the first day in the unfamiliar U maze presumably would be controlled by chance factors, such first-day scores were not included in any basic data except in preparing graphs showing trends during the learning period.

In Table 2 is a presentation of the means of the total errors made by the *Ss* in each group during 30 trials (the first trial not included). "Total errors" here includes both forward-going and retracing errors. In Table 3 are the variance estimates, the variance ratios, the degrees of freedom, and the probabilities which indicate the levels of significance of the differences between the means presented in Table 2.

Referring to Table 3, one notes that the between-rows effect, i.e., the difference in mean error scores for ECS versus nonshock (pseudoshock) groups, is significant at the .001 level of confidence. Also in table 3, it may be noted that the between-columns or ionization effects were not statistically significant.

The time-score data were summarized and analyzed in a manner similar to that for error scores (see Tables 4 and 5). One notes here that the difference between the row means for time scores is significant at the .001 level of confi-

TABLE 2

Mean Errors in Maze Learning

Treatment	Positively Ionized Air		Negatively Ionized Air		Normal Air (Control)		Row Mean
	Group	Mean	Group	Mean	Group	Mean	
Pseudoshock	I	57.56	III	58.52	V	55.95	57.34
ECS	II	93.95	IV	87.17	VI	95.13	92.08
Column mean		75.76		72.84		75.54	

TABLE 3

VARIANCE TABLE FOR ERRORS IN MAZE LEARNING

Source	*df*	Variance Estimate	*F*	Probability
Rows (ECS)	1	41,634.85	41.13	$p < .001$
Columns (ions)	2	121.13	0.12	$p > .05$
Interaction	2	341.83	0.33	$p > .05$
Within groups	132	1,029.18		

dence. In terms of mean time scores, then, as well as in terms of error scores, the over-all differences between shock and nonshock groups are highly significant. One can safely conclude that real effects on learning ability are produced by a series of 10 electroconvulsive shocks. But there is no statistical evidence that the maze learning of the rats was affected either favorably or unfavorably by the differences in atmospheric ionization.

Graphical analyses of the data provide a somewhat better picture of the trends or stages in the maze tests. The curves in Fig. 5 and 6 represent the mean daily error and time scores for the six groups of rats. The graphs for total error scores (Fig. 5) and for total time scores (Fig. 6) show that the ECS and the pseudoshock (nonshock) groups were clearly differentiated during and immediately after the shock period. However, there appear to be no characteristics by which the curves can be differentiated to provide evidence of ionization effects on the rate of learning.

It is of interest to note how very closely equated the groups were on the first trial when presumably only chance factors influenced the scores. However, as trials continued during the ECS and pseudoshock period, the ECS groups in contrast with the pseudoshock groups,

TABLE 4

MEAN TIME SCORES IN SECONDS FOR MAZE TRIALS

Treatment	Positively Ionized Air		Negatively Ionized Air		Normal Air (Control)		Row Mean
	Group	Mean	Group	Mean	Group	Mean	
Pseudoshock	I	1086.65	III	1039.30	V	983.60	1036.52
ECS	II	1219.78	IV	1263.82	VI	1177.13	1220.24
Column mean		1153.21		1151.56		1080.36	

TABLE 5

VARIANCE TABLE FOR TIME SCORES FOR MAZE TRIALS

Source	*df*	Variance Estimate	*F*	Probability
Rows (ECS)	1	1,164,538.62	14.57	$p < .001$
Columns (ions)	2	79,567.40	1.00	$p > .05$
Interaction	2	24,840.92	0.31	$p > .05$
Within groups	132	79,903.39		

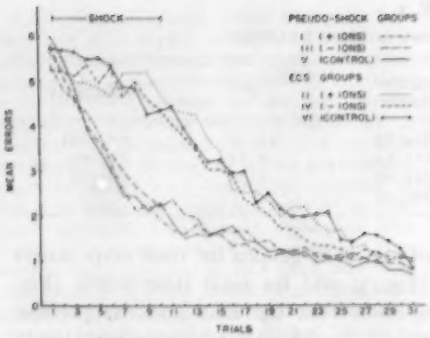

FIG. 5. Learning curves based on mean error scores for the maze trials.

showed little evidence of learning; the corresponding curves diverged widely. The gradual recovery from the adverse effects of ECS is indicated by the trend of the learning curves after the shock period. By the end of the experiment the six groups were again indistinguishable in terms of maze behavior.

B. *The Nest-Building Experiment*

Reliability of the rating scale. It appears logical that, in analyzing the data, first consideration should be given to a test of the reliability of the rating scale used in acquiring the data for this study. For this purpose Pearson product-moment correlation coefficients (r's) were computed for each of the 32 successive sets of daily ratings that were made independently by the experimenter and by Professor Calvin P. Stone. Each of the first 29 r's was computed for a set of 16 correlated ratings; each of the last 3 was computed for a set of 12 correlated ratings. The r's ranged from .71 to 1.00 with a mean of .91. Three correlations under .80 occurred when the range of scores was severely curtailed.

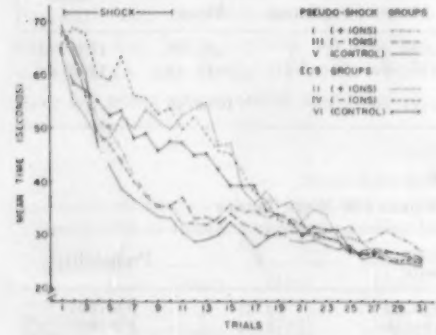

FIG. 6. Learning curves based on mean time scores for the maze trials.

It was deemed inadvisable to combine all 500 correlated ratings in order to compute a single r, since some of the data represented successive ratings made on the same group of nests. Therefore, the mean of the 32 separately computed correlation coefficients is presented as the best estimate of a reliability coefficient for the rating scale. That coefficient (mean $r = .91$) indicates that the scale is a reasonably reliable instrument in the hands of raters who have had considerable pratice in its use.

Graphic representation of the data. To achieve a clear over-all view of the differences in nest building and its daily progress under the various experimental conditions, it may be useful to present first a graphic analysis (Fig. 7) of the data for the five groups during the 12 rating intervals. The graph indicates first of all that the shock groups appear to be differentiated clearly from the nonshock groups, especially in the early part of the nest-building period. However, the significance of these differences, as well as the possible significance of the smaller differences among Groups A, B, and C, can be judged better after a statistical analysis of the data.

The curves in Fig. 7 are of further interest in that they indicate the gradual return of nest building as the shocked animals gradually recovered from the effects of ECS. Rating Number 12 which was made eight days after the last shock was administered indicates that the ani-

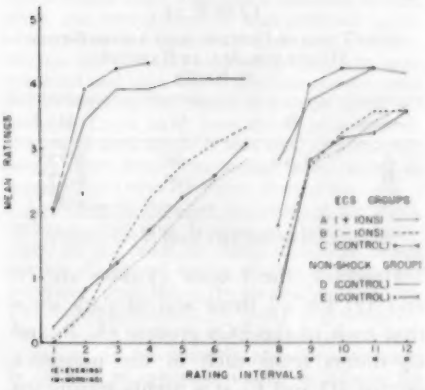

FIG. 7. Curves indicating the progress in nest building by five groups of male white rats. The breaks in the curves between ratings 7 and 8 mark the point at which the old nests were broken up by the experimenter and the construction of new nests was begun by the rats.

mals had not yet fully recovered, though considerable progress had been made.

Statistical analysis. A summary of the data on nest building in terms of mean ratings for the five groups is presented in Table 6. The mean given for Group E includes only the first evening rating and all six morning ratings; the second evening rating was not included. By this arrangement the data for Group E are made comparable to the first seven ratings of the other four groups.

A further analysis of the data required an over-all test of the significance of the differences between the group means for each set of data with all the groups concerned considered simultaneously. For this purpose Bartlett's test of homogeneity of variance (24) and a simple analysis of variance were made for each of the three sets of data which have been summarized in Table 6.

The results of the analyses of variance are presented in Tables 7, 8, and 9. As can be seen there, the *F*s are highly significant for all three sets of data. This indicates that in each case the between-groups variance estimate is significantly larger than that within groups and that for each set of data the group means do

TABLE 6

MEAN RATINGS OF NESTS BUILT BY MALE WHITE RATS

Group	Mean of First 7 Ratings	Mean of Last 5 Ratings	Mean of All 12 Ratings
A	10.42	13.58	24.00
B	13.33	14.42	27.75
C	12.00	13.50	25.50
D	25.50	19.00	44.50
E	27.08*		

* Mean based on only the first evening rating plus all six morning ratings made for Group E.

TABLE 7

VARIANCE TABLE FOR FIRST SEVEN RATINGS OF NESTS

Source	*df*	Variance Estimate	*F*
Between groups	4	760.46	55.66*
Within groups	55	13.66	

* Significant at the .001 level of confidence.

TABLE 8

VARIANCE TABLE FOR LAST FIVE RATINGS OF NESTS

Source	*df*	Variance Estimate	*F*
Between groups	3	82.14	9.96*
Within groups	44	8.25	

* Significant at the .001 level of confidence.

TABLE 9

VARIANCE TABLE FOR ALL 12 RATINGS OF NESTS

Source	*df*	Variance Estimate	*F*
Between groups	3	1083.19	28.64*
Within groups	44	37.82	

* Significant at the .001 level of confidence.

TABLE 10

THE *t* TESTS OF DIFFERENCES AMONG GROUP MEANS FOR FIRST SEVEN RATINGS OF NESTS

Group	B	C	D	E
A	1.93	1.05	9.99*	11.03*
B		.88	8.06*	9.11*
C			8.94*	9.99*
D				1.05

* Significant at the .001 level of confidence.

differ significantly among themselves. In each case, therefore, one can conclude with a high level of confidence that the pertinent sets of scores have not been drawn from the same population of scores and that at least some of the differences in experimental arrangement are a real source of variation.

After finding that the over-all *F* for each set of scores was significant, it was permissible to use the *t* technique to test the significance of the differences between any pair of group means in a specific set of scores. The *t* values are presented in Tables 10, 11, and 12.

The given *t* tests for the three sets of data indicate that in all cases the differences between pairs of means for Groups A, B, and C are not statistically significant. Therefore, for those comparisons the null hypothesis cannot be rejected. Thus we have no evidence to support the hypothesis that positively or negatively ionized air could modify the deleterious effects which ECS has on nest-building behavior.

TABLE 11

THE *t* TESTS OF DIFFERENCES AMONG GROUP MEANS FOR LAST FIVE RATINGS OF NESTS

Group	B	C	D
A	.72	.07	4.63*
B		.79	3.91*
C			4.70*

* Significant at the .001 level of confidence.

TABLE 12

THE *t* TESTS OF DIFFERENCES AMONG GROUP MEANS FOR ALL 12 RATINGS OF NESTS

Group	B	C	D
A	1.49	.60	8.17*
B		.90	6.67*
C			7.57*

* Significant at the .001 level of confidence.

However, the *t* tests (Tables 10, 11, and 12) for all three sets of data show that each of the ECS groups (A, B, and C) differs from each of the nonshock groups (D and E) at a highly significant level ($p < .001$). One can therefore safely reject the null hypothesis in reference to these data and assume that ECS produces real differences in nest-building behavior.

V. DISCUSSION

A. *Evaluation of Procedure and Results*

In giving further consideration to the results, it may be appropriate to consider the question of whether or not unipolarly ionized air was produced in a quantity and quality that would satisfy the demands of the investigation. Since the ions were created by a polonium source, one can be quite certain that no ozone or other noxious products were produced. General ventilation factors were regulated by a satisfactory rate of air exchange. But three other factors remain to be considered: (*a*) the size of the ions produced, (*b*) the concentration of ions in the atmosphere, and (*c*) the duration of exposure to the ionized air.

The atmospheric ions used in the maze-learning and nest-building experiments were of the small molecular type which have a relatively high degree of motility. Chizhevskii (5, 6, 7, 8, 9), Herrington and Smith (17), Yaglou and his associates (30, 31, 32), Chase and Willey (4), Holloway (18), Danforth (10), and Sokoloff and his associates (12, 25, 26) are among those who have used small ions in their research. (The last

four obtained small ions from a polonium source, while the others used a high-potential point source.) Dessauer (11), Herrington (15), and Herrington and Kuh (16) are among those who have produced and used ions of medium mobility and size in studying the effects of ions on living organisms. There have been claims of success in the use of both kinds of ions and, as previously noted, there have been studies which failed to support the claims for either kind of ion.

According to Dessauer (11) most of the small, molecular-type ions, because of their high motility, do not reach the lungs of human beings but are discharged on the mucosa of the upper respiratory tract before the air reaches the lungs. The external surfaces of living organisms are also exposed to the action of atmospheric ions. There are no data from the measurements made in these or in any other studies to indicate the degree to which small ions are discharged in the lungs of the rat, on its mucosa, or on its other body surface areas. But Dessauer's (11) concern with whether or not the ions reached the lungs would have to be given greater consideration only if there were evidence that ions must enter the blood stream through the lungs as he hypothesized, or if there were evidence that ions affected the rate of oxygen absorption from the lungs. Since there is as yet no published evidence to support either assumption adequately, there is less reason to be concerned with whether the ions reach the lungs or whether they are discharged elsewhere on the body. Since light ions occur in varying quantities in the normal atmosphere, it is logical to test for possible effects of such variations on living organisms irrespective of how such effects may be achieved.

To be noted is the fact that during the maze-learning experiment the median ion concentration was 6000 positive small ions per cc. in the positively ionized chamber and 3500 negative small ions per cc. in the negatively ionized chamber. During the nest-building experiment the median ion density was 6500 positive and 3000 negative small ions per cc. in the respective chambers. These are much smaller ion concentrations than were employed by Dessauer (11), Herrington (15, 16, 17), Yaglou (30, 31, 32), and most of the other original experimenters in this field. However, the concentrations reported above are comparable to the ion densities reported in recent research studies (10, 12, 18, 26), some of which allegedly have provided evidence of effects of ionization on living organisms.

Engineers employed by the Wesix Electric Heater Company, who designed the ionizing equipment used in these experiments, have been working on the principle that if atmospheric ions did have any effect on living organisms, it would be better to test them in nearly the same general range of density as they are found in nature (2). Emphasis has been on a strong predominance of negative over positive ions in the negatively ionized chamber and on a strong predominance of positive over negative ions in the positively ionized chamber. It may be noted that in the control chamber the median measurement of each kind of ion was relatively small with nearly the same number of ions of each kind in the air.

A question may be raised about the fact that the experimental groups were not in ionized air during the actual learning trials and for a brief interval thereafter. If further learning tests were to be made, it would not be impossible to ionize the air of the entire maze room appropriately for the various groups. There is also a second feasible alternative. This would be to place strips of glass or of firm transparent plastic over each of the maze alleys. Then the outlets of inverted ion generators could be inserted through holes in the glass or plastic covering. Thus the highly ionized air would be concentrated between the water and the transparent cover which would be 7 in. above the water level. Appropriate ion generators could also be placed in the goal box and in the drying chamber. However, nothing observed in the completed studies gives any indication that such changes in the experimental procedure would have materially altered the given results. Also, earlier studies which had produced extensive claims for the effects of ionized air had not employed a continuous exposure technique. There is no reason to believe that highly transient effects were produced but lost during the brief periods when the *Ss* were outside of the ionization chambers.

A similar question could not be raised about the nest-building experiment; those *Ss* lived in appropriately ionized air continually during the course of the experiment except for the very brief intervals when shock was administered and when nesting material was being placed in the cages. In that experiment, the test was of behavior which occurred while the animals were living in the ionized atmosphere, but there was no statistically reliable evidence that the ions in any way affected such behavior.

Some of the earlier studies (8, 11, 17) have suggested that any ionization effects would be cumulative. If such effects are cumulative, it is possible that they may require a longer period for development than was allowed in the maze- and nest-building experiments. It is suggestive that in Herrington and Smith's study (17) rats were exposed to ionized air from the age of 21 days to 300 days of age, but what appeared to be significant differences developed only after the rats were approximately 175 days old.

On the other hand, in Holloway's study (18) of the physiological effects of ionized air upon the

growth and pituitary-adrenal system of the rat, there was a suggestion that changes of a "cyclical character" occurred depending on the duration of ionization. If the cyclical nature of physiological effects of ionization was to be further confirmed, it might be desirable to plan some psychological tests so that each measurement of behavior was made at the same point of the given physiological cycle. But observations from the present learning- and nest-building experiments offer no evidence of cyclical variations in behavior.

In choosing the problems for this research, consideration was given to the fact that there was not yet definite evidence that ionized air affected brain processes. But it was expected that if differential effects on behavior could be produced by positive and negative ions, then the results of the psychological tests would be indicative of basic physiological and biological effects produced by the ions.

Since no behavioral differences that could be ascribed to unipolarly ionized air appeared in these experiments, two alternative conclusions are possible. One is the possibility that the behavioral tests used were not satisfactory indices of physiological processes which might have been affected by the ions. The other alternative is that no behavioral effects appeared simply because no underlying biological or physiolcgical processes were affected by the ionized air. The results of the given experiments do not enable one to determine which of the alternatives is the correct one, but unless new evidence appears to support the first possibility, the second alternative is more acceptable.

Because the "null hypothesis" cannot be proven, one cannot say that the results of these experiments are proof that unipolarly ionized air has no effects on the learning and nest-building activity of white rats. Therefore, these studies do not close the question as to possible cumulative effects of artificial atmospheric ionization on behavior. But nothing was observed that would lead one to expect that the ions did produce any effects on the *Ss*; unless new evidence from carefully controlled, repeatable studies is presented eventually, the hypotheses which are not so supported must be abandoned. As of now, the hypotheses concerning effects of ionized air on learning and nest-building activity remain unproven, and these studies must be ranged beside others which have failed to support theories concerning effects of ionized air on living organisms.

B. *Proposals for Further Research with Unipolarly Ionized Air*

A discrimination test. In the report by Dessauer (11) of the work of his associates in Germany, it was alleged that some human subjects showed a preference for negatively ionized air which was described as exhilarating and invigorating; in contrast, positively ionized air appeared to be unpleasant and occasionally produced headache, dizziness, and nausea. If it may be postulated that animals such as rats will show a preference or an avoidance due to differential subjective reactions to ionized air of differing polarities, a simple discrimination experiment may be designed.

It is suggested that several variables be considered: positively ionized air, negatively ionized air, air containing a high concentration of mixed ions, completely de-ionized air, and normal air containing a small concentration of ions of both polarities. To provide a discrimination apparatus, differentially ionized chambers or cages could be so connected that an animal could move freely from one to another. Discrimination of the differentially ionized atmospheres would be indicated if a subject showed a preference for a specific kind of ion, irrespective of the chamber in which it appeared. To control other factors that might possibly affect a preference or avoidance of a chamber, the ion generators would need to be shifted from chamber to chamber at appropriate intervals and food and water would be available in every chamber. A multi-pen kymograph or a set of electric clocks could serve as an automatic recording device. The floor of each chamber could be so suspended on springs that the weight of an animal entering the chamber would trip a microswitch, setting into operation the mechanism recording the time spent in that specific cage.

As Herrington and Kuh (16) have pointed out, atmospheric ions may influence the suspension in the atmosphere of materials that do have subjective and/or biological effects, though that would not be evidence of an effect of the electrical charge of the ions per se. However, even if the role of ionization were related only to the suspension of dust, pollen, and disease germs in the air, it, nonetheless, would be an important factor worthy of further research and evaluation.

General activity tests. A study by Herrington and Smith (17) has suggested that negatively ionized air produced some effects on the activity of rats. A revolving-drum technique was used to measure the activity. Not only should a study using that type of apparatus be repeated, but activity tests should also be made using tambour-mounted cages and other stabilimeter and recording devices (22, pp. 52-57). It has been suggested that stabilimeter techniques are better than revolving-drum techniques for measuring "general restlessness," and it is considered possible that the activities recorded by the two techniques may differ in "motivational significance" (22, p. 56).

Any study of activity in rats living in ionized

air must take into consideration the possibilty of producing cutaneous sensations if there is an accumulation of static on the fur and vibrissae. Herrington and Smith (17) have indicated that this quite probably was not a factor producing the increased activity recorded in their study.

A proposed test of bioelectric gradients. The theory that ionization of the surrounding atmosphere may affect the electrodynamic fields or electrostatic gradients within the body has been discussed by Sokoloff (25, pp. 166-179). Behavior tests presumably may reflect such biological and physiological changes. The possibility that changing bioelectric gradients within the organism may be related to its behavior has been indicated in a study by Burge, Wickwire, Orth, Neild, and Elhardt (3). They investigated changing electrical potentials in the cerebral cortex in relation to anesthesia, consciousness, and unconsciousness. It was found that in dogs under anesthesia, the cortex was electropositive in relation to the sciatic nerve; with lessening of anesthesia, there was a reversal of polarity. When anesthesia was again increased, a positive polarity again appeared. Unconsciousness produced by bleeding or suffocation also produced changes in cortical polarity. To Burge and his collaborators (3), it appeared that consciousness is in some way related to the electrical potential of the cortex, since active tissue is electronegative and inactive tissue is electropositive.

The foregoing study suggests the possibility of making direct tests of bioelectric gradients within the body of an organism to determine whether ionizing the surrounding atmosphere produces any changes in the gradients. Such biological evidence would be desirable even if behavior studies eventually were able to give conclusive indications of ionization effects. The biological evidence, if obtainable, might suggest the mechanism by which effects on behavior could be produced.

VI. Summary

1. The review of a large and controversial literature indicated that ventilation engineers, hygienists, and therapists still are interested in the question of whether a predominance of negative or of positive ions in the atmosphere produces any effects on living organisms. The basic hypotheses are that negatively ionized air is essentially beneficial in its effects on biological, physiological, and psychological processes, whereas positively ionized air is detrimental.

2. To test for effects of unipolarly ionized air and electroconvulsive shock (ECS) on learning, 138 male white rats, divided equally among six groups, were given 31 daily trials on a multiple-U water maze. Groups I and II lived in positively ionized air (6000 positive small ions per cc. of air), Groups III and IV lived in negatively ionized air (3500 negative small ions per cc.), and Groups V and VI lived in normal air. All groups lived in small chambers in which the ion concentration and the rate of air exchange could be controlled; ions were produced by Wesix polonium-source ion generators. Each *S* in Groups II, IV, and VI was subjected also to one ECS approximately 30 min. after completion of each of the first 10 maze trials.

3. In the second experiment, 60 male white rats, divided equally among 5 groups, were tested for effects of unipolarly ionized air and ESC on one form of innate behavior, nest building, during a period when daily minimum temperatures ranged between 45° and 61° F. Group A lived in positively ionized air (6500 positive ions per cc.), Group B lived in negatively ionized air (3000 negative ions per cc.), Groups C and E lived in normal air in cages in small enclosed chambers, and Group D lived in normal air in cages in a larger room. Subjects in Groups A, B, and C were subjected to one ECS daily for 10 consecutive days.

4. The results of the first experiment provided no evidence that the maze-learning behavior of rats, as measured by time and error scores, was modified in any way by unipolarly ionized air under the given experimental conditions. Hypotheses that negatively ionized air would have a beneficial or facilitative effect and that positively ionized air would have a detrimental or retard-

ing effect on learning were not supported.

5. Analyses of the data provided statistically significant evidence that ECS markedly retards maze learning. But after the shock period there was a gradual recovery from the adverse effects of ECS; at the end of the experiment the shock and the nonshock groups were indistinguishable in terms of maze behavior. However, there was no evidence that any form of unipolarly ionized air either facilitated or delayed this recovery.

6. That ECS has a seriously disruptive effect on the nest-building behavior of male white rats was indicated by both statistical and graphic analyses of data in the second study. After the shock period, there was a gradual return of nest-building activity; however, there was no statistically significant evidence to support hypotheses that negatively or positively ionized air have differential effects on such recovery. The reliability of the nest-rating scale was established (mean $r = .91$).

7. Evidence that unipolarly ionized air was produced in a quantity and quality necessary to satisfy the demands of the investigation was evaluated and the effectiveness of other controls was considered. Suggestions are given for further study of possible effects of ionized air.

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